Chapter 10
Instrumentation

10-1. General

a. Dam safety. In view of concerns for dam safety, it has become increasingly important to provide sufficient instrumentation in earth and rock-fill dams for monitoring the performance of the structure during construction, and for all anticipated stress conditions throughout the operational life of the project. Visual observations and the interpretation of instrumentation data from the embankment, foundations, abutments, and appurtenant features provide the primary means for engineers to evaluate dam safety. In recent years, technology of devices for measuring seepage, stresses, and movements in dams has improved significantly with respect to accuracy, reliability, and economics. Guidance on the selection and use of various types of instrumentation is presented in EM 1100-2-1908, Parts 1 and 2.

b. Instrumentation. Once instrumentation has been installed, a program must be developed to collect data on an appropriate schedule established for each project. A minimum collection schedule is described in ER 1110-2-100. Data must be promptly plotted, summarized, and critically reviewed and evaluated by competent personnel. It is important to realize that installation of instrumentation, without appropriate collection and review of data, does not accomplish the desired end result of evaluating the performance and safety of the structure. Data tabulations and evaluation summaries should be presented for record in periodic inspection reports throughout the operational life of the project.

10-2. Instrumentation Plan and Records

A separate design memorandum should be prepared outlining the proposed instrumentation. This should include a presentation of the following items:

a. The number, location, and type of piezometers, inclinometers, surface movement markers, settlement gages, or other types of instrumentation.

b. A separate plan of each feature of the project with the instrumentation clearly located.

c. A general schedule of installation and frequency of observation.

d. An explanatory discussion of the purpose of the devices to be installed.

e. Threshold limits, along with the predicted performance levels, should be given.

ER 1110-2-1925 prescribes the forms to be used in recording instrumentation observations.

10-3. Types of Instrumentation

The type, number, and location of required instrumentation depend on the complexity of the project. Devices may consist of the following: piezometers (open tube, such as the Casagrande type, electrical, vibrating wire, or occasionally closed systems) located in the foundation abutment and/or embankment, surface monuments, settlement plates within the embankment, inclinometers with telescoping casing, movement indicators (at conduit joints, outlet works, and intake tower), internal vertical and horizontal movement and strain indicators, earth pressure cells, and accelerographs (in areas of seismic activity).

10-4. Discussion of Devices

a. Piezometers. The safety of a dam is affected by hydrostatic pressures that develop in the embankment, foundation, and abutments. Periodic piezometer observations furnish data on porewater pressures within the embankment, foundation, and abutments, which provide a check on seepage conditions and performance of the drainage system. The installation should consist of several groups of piezometers placed in vertical planes perpendicular to the axis of the dam so that porewater pressures and/or seepage pressures may be accurately determined for several cross sections. At each cross section where piezometers are placed, some should extend into the foundation and abutments and be located at intervals between the upstream toe and the downstream toe, as well as being placed at selected depths in the embankment. In addition to the groups of piezometers at selected cross sections, occasional piezometers at intermediate stations will provide a check on the uniformity of conditions between sections. Each piezometer should be placed with its tip in pervious material. If pervious material is not present in the natural deposit of foundation material, or if the tip is in an impervious zone of the embankment, a pocket of pervious material should be provided. Two of the more important items in piezometer installation are the provision of a proper seal above the screen tip and the water tightness of the joints and connections of the riser pipe or leads.

b. Surface monuments. Permanent surface monuments to measure both vertical and horizontal alignment should be placed in the crest of the dam and on the upstream and downstream slopes. Survey control should be maintained from reference monuments located in stable material outside of the limits of influence from the construction. Monuments should be embedded in the embankment by means of a brass or steel rod encased in concrete to a depth appropriate for regional frost action. All monuments must be protected against disturbance by construction and maintenance equipment. Guidance on spacing is as follows: 50-ft intervals for crest lengths up to 500 ft, l00-ft intervals for crest lengths to 1,000 ft, and 200- to 400-ft intervals for longer embankments. These monuments should be installed as early as possible during construction and readings obtained on a regular basis.

c. Inclinometers. Inclinometers should be installed in one or more cross sections of high dams, dams on weak deformable foundations, and dams composed at least in part of relatively wet, fine-grained soils. Inclinometers should be installed particularly where dams are located in deep and narrow valleys where embankment movements are both parallel and perpendicular to the dam axis. It is essential that these devices be installed and observed during construction as well as during the operational life of the project.

d. Miscellaneous movement indicators. Various types of instrumentation may be installed to measure horizontal spreading of the embankment (particularly when the foundation is compressible), movements adjacent to buried structures, foundation settlement, and internal strains. Strain measurements are particularly significant adjacent to abutments and below the crest to detect cracking of the core. Where there is a possibility of axial extension, as near steep abutments, surface monuments should be placed on the crest at 50-ft intervals to permit measurement of deformations along the axis.

e. Pressure cells. The need for reliable pressure cells for measuring earth pressures in embankments has long been recognized, and much research has been done toward their development. Although many pressure cells now installed in earth dams have not proved to be entirely satisfactory, newer types are proving to be satisfactory and increased usage is recommended. Some types of pressure cells installed at the interface of concrete structures and earth fill have performed very well.

f. Accelerographs. For important structures in areas of seismic activity, it is desirable to install strong-motion, self-triggering recording accelerographs to record the response of the embankment to the earthquake motion. ER 1110-2-103 provides requirements and guidance for installation and servicing of strong-motion instruments. EM 1110-2-1908 discusses types of devices and factors controlling their location and use. Digital accelerographs are recommended as replacements for existing analog film-type accelerographs. A status report on Corps of Engineers strong-motion instrumentation for measurement of earthquake motions on civil works structures is provided annually. As of September 1993, the Corps of Engineers has installed 431 accelerographs, 56 peak accelerograph recorders, and 36 seismic alarm devices at 124 projects located in 33 states and the Commonwealth of Puerto Rico.

10-5. Measurements of Seepage Quantities

The seepage flow through and under a dam produces both surface and subsurface flow downstream from the dam. The portion of the total seepage that emerges from the ground, or is discharged from drains in the dam, its foundation, or abutments, is the only part that can be measured directly. An estimate of the quantity of subsurface flow from flow net studies may be based on assumed values of permeability. The portion of the seepage that appears at the ground surface may be collected by ditches or pipe drains and measured by means of weirs or other devices (monitoring performance of seepage control measures is discussed in detail in Chapter 13 of EM 1110-2-1901).

10-6. Automatic Data Acquisition

a. Electronics. Developments in the field of electronics have now made it possible to install and operate automated instrumentation systems that provide cost-effective real time data collection from earth and rockfill dams. Installation of these computer-based automatic data acquisition systems (ADAS) satisfies the growing demand for more accurate and timely acquisition, reduction, processing, and presentation of instrumentation data for review and evaluation by geotechnical engineers. Consideration should be given to providing an ADAS for all new dam projects. General guidance for developing an ADAS is presented in Appendix D. A database for automated geotechnical and some structural instrumentation at Federal and non-Federal projects is maintained under the Corps of Engineers Computer Applications in Geotechnical Engineering (CAGE) Program.[1]

[1] Additional information is given in ETL 1110-2-316, Data Base for Automated Geotechnical Instrumentation.

b. Automatic data acquisition systems. It is also advantageous to retrofit existing projects with an ADAS if one or more of the following conditions exist:

(1) The project is located in a remote area, far from the District office where instrumentation data would be difficult to obtain during critical operating conditions.

(2) Because of a shortage of manpower at the project, it would be difficult to obtain a sufficient number of manual instrumentation readings when extreme loading conditions exist.

(3) Where geotechnical engineers have a need for either more accurate and/or more frequent readings than operations personnel can supply.

(4) If rapid data processing and presentation of instrumentation data for review and evaluation is necessary. For example, it is now possible with the use of ADAS to force readings at any time, see those readings immediately in the District office, and within an hour, have the data plotted for presentation.

(5) Where it is economically cheaper to purchase, install, and maintain an ADAS.